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Agronomic techniques to reduce quelea damage to cereals

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Introduction

Careful attention to planting schedules, cropping schemes, husbandry practices, and selecting less susceptible cereal varieties can reduce quelea damage to cereal crops in Africa. Linked to the ingenuity and skills of African farmers, agronomic methods may reduce the dependence of traditional farmers on national or regional lethal control units to protect their crops.

Cereals are important members of the grass family Gramineae, which together with Leguminosae comprise most of the world's food sources (Harrel and Dirks 1955). Wheat *Triticum aestivum*, Barley *Hordeum vulgare*, Rice *Oryza sativa*, Maize *Zea mays*, Sorghum *Sorghum bicolor*, and Millet *Panicum* spp. are all found in Africa and suffer bird damage.

Wheat and barley were domesticated about 7000 BC in the Middle East, before coming to Ethiopia and the rest of Africa (Doggett *et al.* 1970). These crops are now grown in the more temperate zones of Africa. Sorghum cultivation began later and probably originated in north-east Africa (Doggett 1970). The tolerance of wild sorghums to hot lowland conditions may have favoured their development; sorghum cultivation supposedly spread west and then south.

Many sorghum and millet types are found on the continent because early agriculturists in Africa were able to select the characteristics most suitable for the various altitudes, rainfall conditions, tolerance to insects and diseases, and soil types. Because sorghum and millet have a greater yield stability over such a wide range of environmental conditions compared to other cereals, they have had a major place in African agriculture. In addition to the widely varying sorghum varieties, culture and uses differ appreciably in eastern, western, and southern Africa. From Ethiopia and Sudan southward,

sorghum is considered an important cereal for human food consumption and brewing. Plant height, panicle and grain types, and maturation period vary greatly among regions and sorghum cultivars (Doggett *et al.* 1970).

Great variability also exists in plant, head, and seed characteristics of African millets. Pearl millet *Pennisetum typhoides* is the most widely grown African millet (S. Clarke, pers. comm.) and one of the most drought-tolerant of all cereals. Early-season millet matures within 60–95 days, whereas late-season millet matures within 130–150 days (Hulse *et al.* 1980). Finger millet *Eleusine coracana* is found primarily in eastern and central Africa, and probably is the next most important variety. In addition, a number of minor, localized, small-seeded cereals exist that usually are listed in the millet category (S. Clarke, pers. comm.).

The exposed seeds, the strong stalk, and leaf characteristics make sorghum and millet highly vulnerable to quelea damage. The sorghum varieties usually grown for food have white, corneous grains that can be ground into white flour. Quelea also prefer these varieties, and in some areas of Africa damage has been so severe that farmers have turned to maize instead. For example, sorghum is not widely grown in the hot subtropical zone of the Awash River Basin of Ethiopia, even though it is the cereal most suited to the low and erratic rainfall (Erickson 1979). The same is true for much of the rest of the Great Rift Valley and other lowlands of eastern and southern Africa.

Plant breeding concepts of less susceptible varieties

Breeding cultivars that are less susceptible to or less preferred by granivorous birds is a popular means to minimize losses. Harris (1969) defined bird resistance as 'that mechanism or characteristic of a variety that when given a choice of feeding material birds will not normally depredate.' By this definition, bird resistance is affected by alternative feeding sources, bird population levels, and several other factors. Therefore, even the least susceptible varieties may be destroyed when bird pressure is high.

One strategy of plant geneticists has been to impart morphological or chemical characteristics to a plant or seed that will make it less attractive to birds as a food source (Plate 16). Unless birds become 'sick' (Rogers 1978a), it is improbable that cereal varieties can be developed that will totally resist attack when birds are hungry and have no alternate food; but losses can be substantially reduced in many situations. Doggett (1957) observed that 'varieties may be bred which are unattractive to birds, and which are attacked only as a last resort.' Preferences in feeding behaviour can be a powerful tool if applied properly. An effective way to make a variety less susceptible to bird damage is to combine several characteristics to make it as difficult as possible for birds to eat the grain.

Chemical factors

Astringent tannins are the best known chemicals associated with bird resistance in sorghums and millets. The astringency, producing that mouth-puckering sensation, results from binding of the proteins of the saliva and mucous epithelium by combination with the tannins (Joslyn and Goldstein 1964). Plant breeders working on bird resistance in sorghums have emphasized tannins and African farmers have traditionally selected brown sorghums containing tannins as a means of reducing bird damage. If a choice is available, quelea will seldom prefer the astringent varieties. A direct relationship has been shown between condensed tannin content of sorghum grains and repellency to Red-winged Blackbirds *Agelaius phoeniceus* and quelea (Bullard *et al.* 1980), but in the absence of alternative food, even those sorghums may be ravaged.

The condensed tannins, composed of procyanidin oligomers are located in the grain testa and the pericarp of some varieties. Their biochemical properties such as enzyme inhibition, grain weathering, tanning of hides, deleterious nutritional effects, and astringency are all related to protein-binding properties. Tannin composition and properties are inherited traits. The capacity of tannins to form strong cross-links with proteins is broadly related to size, structure, and shape of the tannin (Goldstein and Swain 1963; Quesnel 1968) and of protein molecules (Hagerman and Butler 1980). More specifically, binding depends on the number of separate sites on the tannin molecule that can bind with sites on the particular protein.

Astringent tannin oligomers are present in the early milk stage of grain development (Bullard *et al.* 1981). The synthesis process apparently begins as chlorophyll develops in the pericarp (Gupta and Haslam 1980). Usually, tannin concentration increases during the milk and early dough stage and then decreases during grain hardening and ripening. Even within the same variety there are variations depending on temperature, sunlight, date of flowering and soil conditions (Hoshino and Duncan 1981; Mabbayad and Tipton 1975). Too much protein-binding activity often remains in the harvested brown sorghum grain and affects its palatability, digestibility, and nutritional quality (Bullard and Elias 1980). These negative factors have given brown sorghums a bad reputation and generally resulted in lower market values.

Sorghums are classified into three groups (I, II, and III) on the basis of their polyphenolic properties. The non-tannin types without a testa are classified as Group I. The testa-containing sorghums are classified as either Group II or III, based on differences in response to vanillin and modified vanillin assays (Price *et al.* 1978). Group III sorghums have similar values for both assays, whereas the modified vanillin values are much higher than those for the vanillin for Group II varieties. Apparently, tannins in Group II

sorghums express their protein-binding activity only in the immature stages, not in the ripened, physiologically mature grain. Group II sorghums are nutritionally equivalent to non-tannin Group I varieties (Hartigan 1979; Oswalt 1975). Bullard (1979) and Bullard *et al.* (1981) have found tannin activity to be consistently lower for Group II sorghums at all maturation stages. Recently, purple testa sorghums were recognized as belonging to Group II (York *et al.* 1981, 1983).

The expression of polyphenolic properties in ripening Group II and III varieties is quite different. Eight ripening hybrids were compared by three chemical, three biochemical, and quelea preference assays (Bullard *et al.* 1981). All hybrids showed an increase in polyphenol activity that peaked in the dough stages and then dropped sharply in mature grain. Group II tannin protein-binding activity tended to peak earlier during grain development and then drop much lower in the ripened grain. Recently, purified tannins from a Group II sorghum (IS 8768) and Group III sorghum (DeKalb BR-64) were compared, and no significant differences were found in their properties (Asquith *et al.* 1983). Apparently, other grain components had an influence on the expression of protein-binding properties in IS 8768.

The major obstacle yet to be overcome is the development of Group II varieties that have enough tannin activity in their immature stages to deter attack from moderate to high bird feeding pressure. At least three Group II hybrids have been found with tannin activity in the milk and early dough stages which is comparable to activity of the most repellent Group III hybrids, but then exhibit the loss in tannin activity characteristic for the mature stage (Bullard and York 1985).

Processing techniques for Group III sorghums

Numerous efforts, other than plant breeding, have been directed toward improving the palatability and nutritional quality of harvested Group III sorghum grain. Some of these efforts may result in methods that can be integrated into economic food processing systems characteristic of those used in other cereals. Mechanically dehulling sorghums has been practised in Africa for years. The pericarp (bran) is removed by vigorous pounding in a mortar and pestle. Sorghum usually decortic peace into quite large flakes (Shepherd 1981). Hand-pounding is tedious, taking about an hour to process 2 kg of sorghum (Munck *et al.* 1982). Thus, there is a ready market for small, diesel-driven village mills serving individual farmers.

The dry milling process for sorghum grain varies from cracking to bran and germ removal. In a pilot village-scale sorghum milling operation in Nigeria, abrasive-type mills have proven superior to attrition-type mills (Reichert and Youngs 1977a). Subsequently, a small batch mill was developed for local milling of sorghum (Munck *et al.* 1982). Further modifica-

tions to permit continuous milling have been used successfully in Botswana (Eastman 1980). Sorghum dehullers are being tested in several East African countries including Ethiopia, Sudan, Kenya, and Tanzania.

The current milling practices may not provide a satisfactory solution to eliminate tannins. First, the techniques are expensive. Second, the milling properties of brown sorghum are generally inferior to corneous endosperm sorghum without testa. Third, important grain constituents are lost in the dehulling process. Reichert and Youngs (1977b) found that 31–51 per cent of 9–18 per cent protein was lost in mechanical dehulling, while 7–21 per cent oil and 5–9 per cent protein was lost in the traditional mortar and pestle technique in Nigeria. Chibber *et al.* (1978) also found that approximately 12 per cent of the grain was lost in each of the three dehulling replications. Up to 37 per cent of the grain and 45 per cent protein was lost in this process that removed up to 98 per cent of the tannins. Furthermore, dehulling caused a decline in the content of lysine, the most limited amino acid in sorghum.

Some African farmers soak Group III sorghum grain in wood-ash or lime during food preparation, to reduce tannin activity. Chemical dehulling can be achieved with a 20 per cent solution of NaOH at 75°C, which removes the pericarp in 4–8 min and leaves the endosperm and germ intact (Blessin *et al.* 1971). Mixing dilute NH₄OH into whole Group III sorghum seeds or dilute K₂O₃ with ground grain (Price *et al.* 1979), extracting with aqueous alkali followed by washing in hot water (Armstrong *et al.* 1974), and soaking seeds in dilute formaldehyde solution (McGrath *et al.* 1982), H₂O, HCl, or NaOH followed by storage under CO₂ atmosphere (Reichert *et al.* 1980) have all led to reduction in tannin activity (Mitaru *et al.* 1983). Likewise, certain methods of processing grain sorghum, such as steam-flaking, reconstitution before grinding, or micronizing (rolling and dry heat treatment) may enhance the food value of the grain (Farris 1975).

With these techniques, it is unlikely that any tannin is lost. It probably either becomes too highly polymerized to remain active, or it becomes tightly bound to other grain constituents (Bullard *et al.* 1981). Unless milled, the ground product will still be red to brown in colour, as would be the case with Group II sorghums. Presently, most consumers tend to treat these products as being inferior because of their colour (Rooney and Murty 1982). Hopefully, with appropriate extension programmes these attitudes may be changed.

Some Finger Millet varieties have testae that contain tannins. Ramachandra *et al.* (1977) found that tannins, phenols, and *in vitro* protein digestibility (IVPD) of several varieties with white seeds had low total phenol and tannin values; dark brown seeds had high values. Two African varieties (IE 927 and IE 929) had high tannin values and had extremely low IVPD values compared to other cultivars.

Morphological factors

For all cereals, plant morphological characteristics can influence bird damage by grain-shielding or perching effects which makes feeding difficult, by 'social' effects of plant foliage creating a feeding environment that is 'stressful' to the bird, and by grain characteristics such as size, shape, hardness, and colour that influence acceptance. These morphological characteristics can be bred into a variety to make it less attractive than alternative food sources.

Stalk characteristics are not seriously considered as a deterrent for quelea. As feeding pressure increases, perching becomes a negligible factor for quelea flocks. Ward (1965a) has described large flocks as advancing across a field like a 'gigantic roller', flattening the crop as it is being stripped. The height of the cereal ears or heads also can be an important factor in choice situations with some species; short varieties can be advantageous. Manikowski and Da Camara-Smeets (1979a) observed that some birds prefer to feed on the tallest stalks. Dawson (1970) observed that the highest ears of wheat and barley suffered the greatest loss to House Sparrows *Passer domesticus*, and no grain was taken from ears lower than 30 cm.

Panicle types

Panicle structure influences susceptibility, especially for sorghums and millets. There is a wide range of variation in the size and shape of panicles, particularly rachis length, number of nodes per rachis, length of seed branches, angle of insertion of these branches, and number and distribution of branches and spikelets in sorghum. Sorghum breeders have introduced the open-headed or lax varieties as one means of reducing bird damage, primarily from blackbirds, but lax panicles are thought to be much more effective deterrents to feeding by large (>50 g) birds. Doggett (1957) observed that quelea seem to be able to perch on the most slender panicle branches of sorghum. Lax panicles would be expected to have some effect on sorghum damage, but probably only in a choice situation where alternative food is readily available. Similarly, Pearl and perhaps Foxtail Millet *Setaria italica* panicles would be easier for quelea feeding than Finger Millet, Japanese Barnyard Millet *Echinochloa frumentacea*, or Common Millet *Panicum milaceum*.

Panicles of some sorghums become recurved after emergence from the sheath. These goose-necked types appear to be less susceptible to birds (Doggett 1957), again because of the inconvenience to feeding. Damage is often on the top side of the curved panicle where it is easier for quelea to perch and feed. Also, in the Horn of Africa and other areas where sorghum

grain matures under low humidity, farmers often plant very compact, large-seeded, goose-necked sorghums of the durra race; Muyra, Abdelot, and Degalit are widely grown Ethiopian varieties of this type.

Awned (bearded) types

Awns, the slender bristles attached to the lemma that covers cereal grains, also can be a deterrent to birds. Adesiyun (1973) observed that 'awns of some varieties of wheat act as natural barriers to attack by birds'. Studies have indicated that awnless varieties are more vulnerable to bird attack than strong-awned types (Jowett 1967; Perumal and Subramanian 1973). In Zimbabwe, quelea preferred the awnless to awned types of wheat growing in large fields containing numerous small plots of different wheat varieties (Plowes 1950). In Liberia, where Black-headed Weavers *Ploceus cucullatus*, Chestnut Weavers *P. rubiginosus*, and Vieillot's Black Weavers *P. nigerrimus* are the most abundant bird pests (Bashir 1984), an awnless rice variety (TOX 502-13-SLR) was damaged significantly more than a variety (ROK 16) having awns with a mean length of 62 mm (Abifarin 1984).

Doggett (1957, 1970) reported that the awnless sorghums are eaten first by quelea, but afterwards the awned types are taken quite readily. Jackson (1971) observed in a test with six caged quelea on awnless, weak-awned (1 cm), and strong-awned (2 cm) varieties of Pearl Millet, that the latter appeared to be comparatively highly resistant to feeding. A field study of awned and awnless varieties of bajra (Indian Pearl Millet) gave similar results (Beri *et al.* 1969).

In addition to lessening bird damage, awns can also be an important factor in increasing grain yield, especially when moisture is scarce (Chen and Li 1980; Shannon and Reid 1976). Studies in both wheat and barley have indicated that awns are an important photosynthetic centre that can contribute significantly to grain growth in the head (Lawlor *et al.* 1979). In wheat, awns seemed to increase the incorporation of N-compounds from vegetative organs to the caryopsis through increased transpiration (Pavlov and Kolesnik 1979). Because awns are a nuisance in mechanical harvesting, plant breeders have selected against this characteristic, possibly at the expense of yield and resistance to bird damage. It may be advantageous for farmers in some areas to return to awned varieties.

Large glumes

Sorghums with large glumes that envelop the grain are widespread in Africa. Perumal and Subramaniam (1973) observed a highly significant difference for glume length in studies where two cultivars with short glumes were more

susceptible to bird damage than one with long glumes. Under low bird pressure, large glumes seem to provide bird protection. Large glumes also are often combined with other traits in attempts to breed less susceptible varieties. One sorghum cultivar, Bishinga Worabeisa, that is found in the Chercher Highlands of eastern Ethiopia, combines large glumes that completely cover the seeds and a very compact, goose-necked panicle. It does not seem to be bothered by birds at all, despite the fact that the seeds are pearly white and of excellent quality. In the United States, lax panicle, awned lemma, and large-glume traits are often combined in brown sorghum hybrids.

Ripened grain size and hardness

If availability and nutritional factors are not considered, quelea probably prefer small grass seeds; therefore size and hardness of cereal grains can influence food choice. Some studies have indicated that quelea prefer grass seeds each of about 1 mg, but eat increasing amounts of smaller (0.3–0.5 mg) or larger (14–30 mg) seeds as 1-mg seeds become scarce. Erickson (1979) observed 'that seed selection is also determined to a great extent by other factors, including the quantities and possibly the qualities of items available. If other seeds are available and the alternate food is ripened cereal grain, the size and hardness can have a definite effect on foraging behaviour.'

Quelea damage can be deterred by choosing varieties that produce very large or hard grains. Doggett (1957) observed that caged quelea would spit out hard grains and suggested that some grains are too large for the beak gape of small birds so that birds have difficulty consuming them. In Chad and Cameroon, Elliott (1979) observed that rice was eaten by quelea at all maturation stages. In laboratory studies, quelea preference for various whole cereal grains was less for wheat than either rice or a medium-sized red sorghum (Elmahdi *et al.* 1985). Size and hardness characteristics apply only to ripened grain. In studies of two Northrup King sorghum hybrids in four stages of maturity, kernel size had little effect on quelea feeding preference during the milk or dough stages, but the smaller grain (NK-1467) was highly preferred over the larger (C-21219) at the ripened stage.

Familiarity and nutritional factors

Food preference behaviour in birds is often influenced by recognition. In some laboratory studies, quelea often refuse unfamiliar food in the presence of a familiar one (Bullard and Shumake 1979). Caged quelea rejected red- or green-coloured millet grain when offered the choice of normal millet, but in the absence of sufficient light to discriminate colour, feeding became random (Shumake *et al.* 1983). This result corroborates that of Da Camara-Smeets

and Manikowski (1979), who found a preference in quelea for naturally coloured grain.

Cereal breeding programmes specifically designed for bird resistance are rare. In view of the seriousness of the problem in Africa, selection for bird resistance should be given high priority, at least as part of overall crop improvement. Breeding programmes for bird resistance must consider several factors among which are useful sources of resistance, effective screening techniques, the inheritance and mechanisms of resistance, and methods of breeding and selection. Sources of resistance, involving the various morphological and chemical factors, could be obtained from various national programmes and the world sorghum collection at the International Crops Research Institute for the Semi-Arid Tropics, but more sources of resistance need to be identified. Major efforts are needed to combine the various sources of resistance into cultivars that have acceptable agronomic, sensory, and nutritional characteristics. Developing standardized screening methods for bird resistance breeding are essential. The most widely used method currently is screening under field conditions where damage usually occurs. The inheritance and mechanisms of bird resistance have not been sufficiently investigated, and more concerted efforts are needed if progress is to be expected.

The best bird-resistant cultivar is perhaps one that carries as many resistance-conferring traits as possible. In addition, the cultivar must be agronomically acceptable in its target area of production. A breeding programme designed to develop such a cultivar must by necessity work with several traits simultaneously. When this is the case, especially when each trait may be polygenic in its inheritance, it is a slow and challenging process. In such a case, perhaps one of the most promising approaches is the use of a recurrent selection scheme. The base population in such an approach must contain as many different types of bird resistance traits as possible and have the desirable range of plant height, maturity, plant type, grain type and size, and other resistance traits. The target variety would have reduced susceptibility to bird damage and produce a high yield of a palatable and nutritious grain.

Crop phenology

Changing crop phenology, for example, planting and maturity dates, is the most discussed agronomic technique for reducing quelea damage to cereal grain crops in Africa (Jackson and Jackson 1977). The bird migration pattern in many areas, where different varieties and planting times can be selected, is such that crops may mature when birds are absent or when an abundant supply of natural food is present (Crook and Ward 1968; Doggett

1957; Plowes 1950; Ward 1973a). Elliott (1979) referred to this as the 'harvest-time' method of bird damage control. Doggett (1982) observed that in northern Tanzania a short-cycle crop planted in February avoided damage at maturity, but in Uganda, crops planted in March–April were later decimated. In the Teso District of Uganda, August plantings of 100- to 120-day sorghum varieties escaped bird damage. Rice grown in the north-eastern corner of Nigeria also escaped damage because it ripens at the end of the rainy season, when the natural food supply is abundant despite the presence of vast numbers of breeding birds (Magor 1974; Ward 1965c).

Manipulating planting dates can be a very practical technique to reduce losses to birds in the semi-arid zone of Africa, if irrigation facilities are available. For example, in the lower Awash River Valley of Ethiopia, irrigated sorghum is planted in September and harvested in December without any quelea damage because the birds are not present during grain development and maturity. In the same area, sorghum planted in December and maturing in March can be completely destroyed by quelea. Elliott (1979) has presented quantitative data indicating that the damage to irrigated rice at Bongor, Chad, and at Yagoua, Cameroon, can be solved in some years by timing the vulnerable stages of the crop to fall between the period of mid-May to mid-June when quelea are absent. Conversely, cereals that mature in the dry season are likely to suffer damage if grown in regions that naturally support large bird numbers (Magor 1974). Areas under dry-season irrigated cultivation often provide the only seed and water in a region and therefore attract birds (Da Camara-Smeets and Manikowski 1979; Ruelle and Bruggers 1982).

Short-cycle varieties most often are used to manipulate harvest times to precede the arrival of birds. Early-maturing varieties have also been important in protecting crops from young quelea. In Bongor and Yagoua, millet, rice, and sorghums usually are attacked between November and January (Jackson 1974c), often by young birds. Quick-maturing varieties occasionally escape this damage because they mature when wild grass seeds are still available. The greatest advantage of short-cycle crops probably is that they are exposed to bird attack for a briefer period during the immature stages. Wild quelea eat about 2.5 g/day (dry weight) of seed, but in a cultivated crop they can destroy more, especially in the immature stages of grain development (Chapter 3; Jaeger and Erickson 1980).

Farmers must plan carefully, co-operate, and know the characteristics of the varieties they use or face severe problems with short-cycle varieties. First, growers whose crop matures much earlier or later than the average usually suffer the most damage from granivorous birds in an area (Meanley 1971; Raju and Shivanarayan 1980). Second, in many areas of Africa, short-cycle varieties must be photoperiod insensitive and resistant to grain moulds (Doggett 1982). Curtis (1968) found that yields of local sorghum varieties are

associated with heading dates. Varieties indigenous to an area flower each year at a time that is associated with the mean date of the end of the growing season. New varieties that mature sooner often face fertility problems and greater exposure to sucking insects and moulds because the rainy season has not ended (Curtis 1968; Doggett 1982).

Several techniques can be used to reduce the period of exposure to birds. Artificial dryers or drying techniques can save valuable grain without reducing seed viability. In Botswana, it was found that sorghum could be harvested as much as 2 weeks early to prevent dove *Streptopelia* spp. losses without impairing germination (COPR 1975). Dimethipin, a plant maturity regulator chemical, when applied during the late season to rice foliage, and 7–14 days before harvest, will reduce seed moisture content at harvest time without affecting yield or milling quality (Blem *et al.* 1983). Finally, C. Elliott (pers. comm.) suggested swathing as a practical early harvesting technique in wheat. In Tanzania, 'swathed wheat appears to be unattractive to quelea which prefer the standing crop or shattered grain.' However, on the 20 000-ha farm in northern Tanzania, where some of these observations were made, he observed that the swathed grain attracts lines of Egyptian Geese *Alopochen aegyptica* and Knob-billed Geese *Sarkidiornis melanotos* but not in sufficient numbers to make a significant impact on the crop.

Other cropping practices

Crop substitution or crop diversification can also be used to decrease bird damage. Maize can be substituted for more susceptible cereals in areas with adequate rainfall requirements. In some situations, damage can be diluted by farmers synchronizing their crop schedules so that damage is spread over a larger area (Feare 1974). Conversely, farmers in some areas of Africa use wide planting dates and stagger their crops so that large numbers of fields in the same maturation stage do not attract massive numbers of birds by the 'local enhancement' phenomenon (Manikowski and Da Camara-Smeets 1979a). Staggered planting can also result from logistical constraints or expected rainfall patterns. Quelea are often more numerous where food is more abundant (Ward 1965a), and local enhancement among the highly gregarious quelea has an important role in food searching (Manikowski and Da Camara-Smeets 1979a). In some cases, crop diversity may result in less bird damage. For example, in the United States, Red-winged Blackbirds gathered in larger flocks in monocultures, flew shorter distances to feed, and caused significantly greater damage than in nearby areas where crops were more diversified (Dyer and Ward 1977).

Planting buffer or diversionary (sometimes called lure or decoy) crops to attract birds away from important cultivars (Farris 1975) may sometimes be

economically justifiable. Another diversionary technique has been to plant high-tannin brown sorghums around the more preferred varieties (Ruelle and Bruggers 1982). Delaying plowing of early-harvested fields until all fields in an area have been harvested will provide alternative feeding sites (such as grain stubble), and possibly thereby make it easier to protect the unharvested fields. Planting seed varieties that mature uniformly can minimize the period of susceptibility and will generally result in a more valuable product.

Clean farming is another way of reducing bird damage (Meanley 1971). Brushy field borders should be cleared to eliminate potential day roosts that may be used during the heat of the day. Brushy areas, especially near rice fields, also harbour insects that attract birds (Woronecki and Dolbeer 1980). Removing brush usually improves the effectiveness of bird-scaring techniques. In Tanzania, a close correlation was found between the presence of weeds in wheat and high levels of quelea damage (Luder 1985a). Clean fields were less attractive. In the USA, blackbirds have been observed to prefer weedy rice fields (Meanley 1971).

Conclusions

The plant genetic and agronomic techniques that we have discussed are potential 'tools' for farmers to use in increasing their food production. Each locality has its own set of conditions that affect farmers. Specialists, trained in most of the above techniques, are needed in each country to help farmers make the proper choices and develop effective programmes. Bruggers and Jaeger (1982) discussed current efforts to transfer the appropriate scientific and technological advances through assistance programmes to government control organizations and agricultural institutions. These efforts need to continue.

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